Pioneer 10 and 11 Mission Support

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The Pioneer 10 and 11 encounters will place the greatest demands of any mission to date on total Ground Data System reliability. The encounter sequence and aspects of the spacecraft design which place demands on DSN performance are described.

I. Introduction

The Pioneer 10 Jupiter encounter will place the greatest demands on total Ground Data System reliability of any planetary mission supported by the Jet Propulsion Laboratory to date. This is principally because of the attempt to execute a complex encounter flyby sequence without the benefit of an on-board sequencer or an on-board data recording system. The encounter sequence, which lasts for a total of 60 days, will involve 14,000 ground commands, essentially all of which are time-critical. The vast majority of these commands are for the operation of a single instrument, the imaging photopolarimeter (IPP). Failure to transmit any of the encounter commands correctly on time will usually result in a loss of some of the science data from this instrument.

Since the science data are not recorded on board the spacecraft for later playback, outages in the real-time ground telemetry system can cause loss of science data from all eleven instruments on board the spacecraft. Such losses will be equal in length to the amount of time it takes to restore or replace the failed element in the ground system. The DSN objective for the critical encounter period is to be able to restore or replace a failed element in the telemetry or command system within 6 minutes.

II. The Imaging Photopolarimeter

The encounter sequence is dominated by the imaging photopolarimeter. The following description of that instrument is provided here so that the origin of the large number of commands required for encounter and their time-criticality may be understood.

The imaging photopolarimeter measures the intensity and polarization of visible light. The instrument consists of an optical telescope, beam-splitting optical prisms, two sets of filtering optics, two channeltron detectors, and signal processing logic and control. The beam-splitting prisms produce two orthogonally polarized beams. Passage through the filtering system results in two color channels, a red and a blue. The instrument has the following operating modes and instantaneous fields of view:

Mode 1, instrument on but not in use.

Mode 2, zodiacal light mode, 40 $\times$ 40 millirad.

Mode 3, polarimetry, 8 $\times$ 8 millirad.

Mode 4, imaging, 0.5 $\times$ 0.5 millirad.

The method in which the instrument scans in order to produce an image is shown in Fig. 1. Scan lines analogous to the horizontal lines in a video system are produced by the instrument looking in a fixed direction with respect to the spacecraft as the spacecraft spins. The start of each scan as the spacecraft rotates is controlled by a series of "spoke" commands which control the start with respect to the spin position or, alternately, the scan can be started by the limb of the planet using the "start data at threshold" mode. For encounter it is planned to use the "spoke" command mode almost exclusively. The equivalent of video vertical scanning is achieved by either stepping the instrument with respect to the spin axis 0.5 millirad between each rotation of the spacecraft or, during the nearest approach to the planet, holding the telescope in a fixed position and letting the relative motion of the spacecraft and Jupiter achieve the scanning. This means that during the closest approach the scan lines can be overlapping or have gaps between them depending upon the relative motion of the spacecraft and Jupiter.

In the imaging mode, the data are converted to 64 levels of intensities (6 bits) and stored in a 6144-bit buffer. The instrument will overwrite this buffer as it starts each "horizontal" scan with each rotation of the spacecraft. The memory read-in time is approximately one-half second and the spacecraft rotation rate is approximately 12 seconds, which means there are approximately 11 seconds available to read out the memory. In order to read out the 6144 bits in the 11 seconds available requires a data rate of 512 bps. The IPP instrument receives about 50% service rate on the spacecraft telemetry downlink, which means that a 1024-bps telemetry downlink from the spacecraft to Earth is the minimum data rate at which all the IPP data taken can be returned to Earth.

The 1024-bps telemetry rate for the time of encounter requires 64-m-diameter antenna coverage. Even with 64-m coverage it may be necessary to reduce the rate to 512 bps at low elevation angles. This will result in returning "horizontal" scans that are only half as long. In the event of a 64-m antenna failure that requires transferring the spacecraft to a 26-m antenna, the bit rate will have to be reduced to 128 bps, resulting in "horizontal" scan lines only one-tenth as long as would be possible at the maximum bit rate. The operation of the instrument in the polarimetry mode, Mode 3, is essentially identical to the above except that the field of view is 8 $\times$ 8 millirad and the automatic stepping is in 8-millirad steps. In addition to stepping the instrument at 0.5 or 8 millirad when in Mode 4 or 3, it is possible to slew the instrument to several fixed positions. The total range of look angles is 151 deg with respect to the spin axis. Between the stops at the limits of the 151 deg are 7 slew stops. The slew stops, referred to as slew angles 1 through 7, are each comprised of 2 stops 1 deg apart. When the instrument is slewed to a slew angle it stops at the slew angle position closest to the direction it is approaching from.

The IPP instrument has an automatic gain control feature. Because this feature does not operate properly on the Pioneer 10 spacecraft, more than twice as many commands will be required during the Pioneer 10 encounter than on the Pioneer 11 encounter.

III. The Imaging Photopolarimeter Encounter Sequence

It is intended to operate the IPP instrument on the order of 8 hours a day for periapsis $\pm$30 days and 24 hours per day for periapsis $\pm$8 days. Figure 2 depicts a typical 24-h IPP encounter sequence. This sequence and the periapsis sequence to be described later are both typical and not the final planned sequence. The chart portrays the look angle as a function of time. The three lines labeled Jupiter are the physical disk of the planet and show its change of position as a function of time. The sinusoidal lines labeled with a J and a Roman numeral depict the look angle of the moons of Jupiter that are in the field of view. The lines labeled SLA1 are the two stop positions of slew angle 1. The irregular line represents the instantaneous look angle of the IPP telescope. Note that this diagram represents only two dimensions in the operation of the instrument. Recall that the look angle is the angle with respect to the spacecraft spin axis and is equivalent to the vertical axis in an ordinary video system. The control of the start of data taking with respect to the roll position of the spinning spacecraft, equivalent to the horizontal scan lines in an ordinary video system, is not depicted.

The basic strategy is to take repeating imaging scans of the disk of the planet, interrupted by slews to a slew angle for polarimetry whenever one of Jupiter's moons crosses a slew angle. Starting at the left of Fig. 1, the IPP instrument is at a slew angle taking polarimetry on Jupiter's second satellite. To get to position 1, 21 commands were required, 12 of which were to overcome the gain control problem. Between points 1 and 7 in the sequence, 5 additional gain control commands are sent at 30-min intervals. At point 7 in the sequence the instrument is commanded into the Mode 3 threshold mode where the instrument slews continuously until the limb is automatically detected. This point in the sequence involves 17 contiguous commands (sent at the maximum command rate of 1 command per 22 seconds), 13 of which are gain control commands to overcome the gain control problem. At point 8 in the sequence the instrument is commanded to the imaging mode (Mode 4) at the imaging rate of 0.5 millirad per spacecraft revolution. This point in the sequence involves 7 contiguous commands, 4 of which are gain control, and 2 are "spoke" commands. Point 9 in the sequence involves a single command to reverse the stepping direction of the telescope. Point 10 in the sequence involves 17 contiguous commands, 16 of which are gain control commands. The sets of commands at points 9 and 10, comprised of 1 and then 17 commands, are repeated at every similar point in the sequence that follows. Step 14 involves 26 contiguous commands, 23 of which are gain control commands, which place the instrument in the polarimetry mode at a slew angle for the crossing of Jupiter's third satellite. The commanding at point 15 in the sequence is identical to that at point 7 and the commanding at point 16 is identical to that at point 8. At point 19 in the sequence, 3 commands are sent which result in switching back to Mode 3 and stepping beyond slew angle 1. The commanding at step 20 reverses the slew to approach slew angle 1 from the correct side to stop at the position that the third satellite of Jupiter is now crossing and involves 32 contiguous commands, 23 of which are gain control.

The rest of the sequence depicted on this chart is built by repeating one of the command sequences already described at the appropriate time. In executing very similar sequences like those which were just described for 8 hours a day from periapsis −30 to +30 days, and 24 hours a day from periapsis −8 to +8 days, the origin of the requirement for 14,000 commands during the encounter sequence is understood.

The possible effects of ground command system problems can be understood by studying this portion of the encounter sequence. When the imaging on the planet is being performed, the look angle is controlled at all points in the sequence similar to 9 and 10 by the time of transmission of the ground commands. If an interruption to command capability occurred at point 9 in the sequence so that command did not leave, the instrument would continue to slew upward away from the disk of the planet. The recovery strategy would have to depend on the length of time it took to restore command capability. If command capability were restored a fairly short time after the schedule transmission time for the command, then the instrument would not have moved too far away from the disk of the planet and that same single command could then be sent to start slewing back toward the disk. A new time of transmission for the set of commands at point 10 in the sequence would have to be computed based on the slew rate and the new look angle that the instrument had to step through. If it took a long time to restore the system after the scheduled time of transmission for the command at point 9, then the instrument would have stepped a large number of degrees from the disk of the planet, and it would be wasting too much time to slew back to the disk. In this case it would be necessary to command the instrument back to the polarimetry mode and slew to slew angle 1 and execute the sequence of commands that would be used at a point such as 15 and 16 to get back to imaging on the disk of the planet.

In either failure case just described, clearly the instrument will end up out of phase with the rest of the planned sequence. When such failures occur, the sequence will have to be caught up at the next scheduled time for polarimetry on one of the satellites. The result will be a loss of some number of imaging scans across the disk of the planet or, to state it differently, the loss of some number of pictures. When the command failures occur near the scheduled time for a satellite observation, then that particular polarimetry viewing of the satellite may be lost.

The above paragraph describes the effect of command system outages on the encounter sequence. There is another category of command failure which has caused a great deal of concern, and that is false verification. False verification of a command means that all system and monitor indicators have indicated that the command was successfully transmitted error-free when in fact it was not.

The effect of false verification could be serious. For example, if the command at point 9 in the sequence was falsely verified, that would mean that the command to reverse scan direction was indicated as successfully transmitted but in fact was not, and the instrument would continue to scan upward away from Jupiter. The round-trip light time at this point in the mission is 90 min, which means that at point 10 in the sequence there would still be no indication that the command at point 9 was not received, and the set of commands at point 10 would be transmitted. At point 11 in the sequence, a round-trip light time would still not have occurred, and the result would be the execution of the mirror image of the planned sequence but up out of the field of view of the planet Jupiter.

It can be understood, then, why false verification is a greater concern for the encounter than detected interruptions to the command capability. In the course of Pioneer 10 and 11 mission support, nearly 30,000 commands have been transmitted and there have been three instances of false verification, the most recent one being in January 1973. The DSN is executing an implementation that will prevent the reoccurrence of the January incident of false verification. The previous two instances of false verification were caused by procedural errors. Since January, several failures which contributed to the previous two cases of false verification have occurred without resulting in a false verification. The DSN will continue to take steps to prevent any future occurrences of false verification.

Essentially the entire 60-day encounter sequence for the IPP instrument, with the exception of the periapsis pass, is built from the command sequences described above relating to Fig. 2. Figure 3 depicts a typical plan for the periapsis pass. Notice the rapidly changing look angle of the planet Jupiter and the satellite viewing in the near encounter. No further examination of the periapsis sequence will be offered here except to point out that, in Fig. 3, each discontinuity in the look angle of the instrument represents an average of about 15 to 20 contiguous time-critical commands.

IV. Conclusions

The DSN is making every effort, within resources, to insure that its portion of the command Ground Data System is as reliable as possible and to minimize the number of command system failures and the resultant loss of IPP data during the encounter sequence. However, there will be some interruptions in command capability during the encounter sequence because equipment and software do fail, and time is required to switch to redundant elements and to restore failed systems. It should be remembered that the command portion of the Ground Data System is comprised of two other elements besides the DSN (project personnel and equipment located at Ames Research Center and Mission Control and Computing Center equipment and personnel at JPL) and that failures in any one of the three elements of the Ground Data System can result in an interruption of command capability. The IPP data that will be lost because of Ground Data System outages during the 60-day encounter sequence is part of the price of flying a planetary encounter mission without an on-board sequencer in order to simplify the spacecraft design and the resulting spacecraft cost.

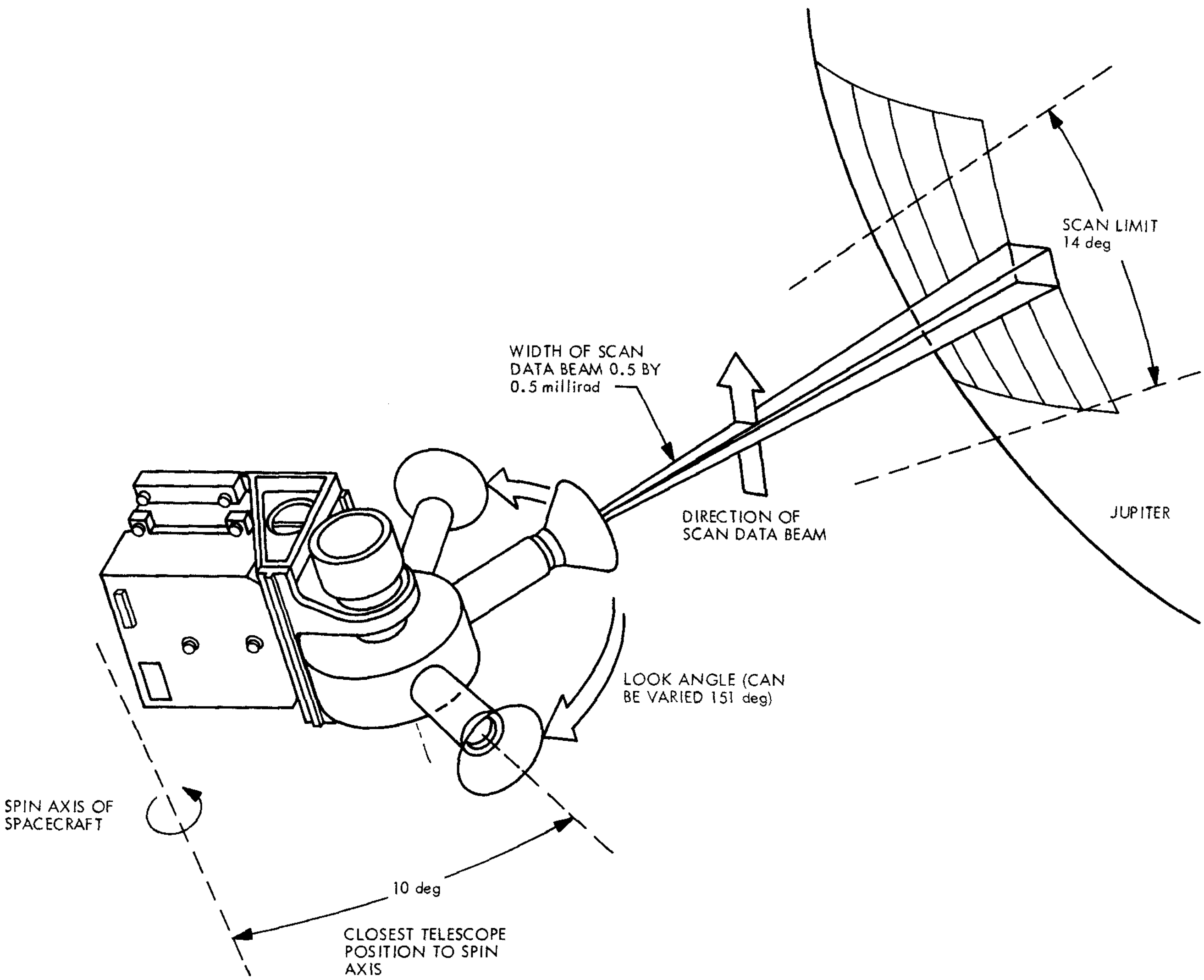

Fig. 1. The IPP imaging system

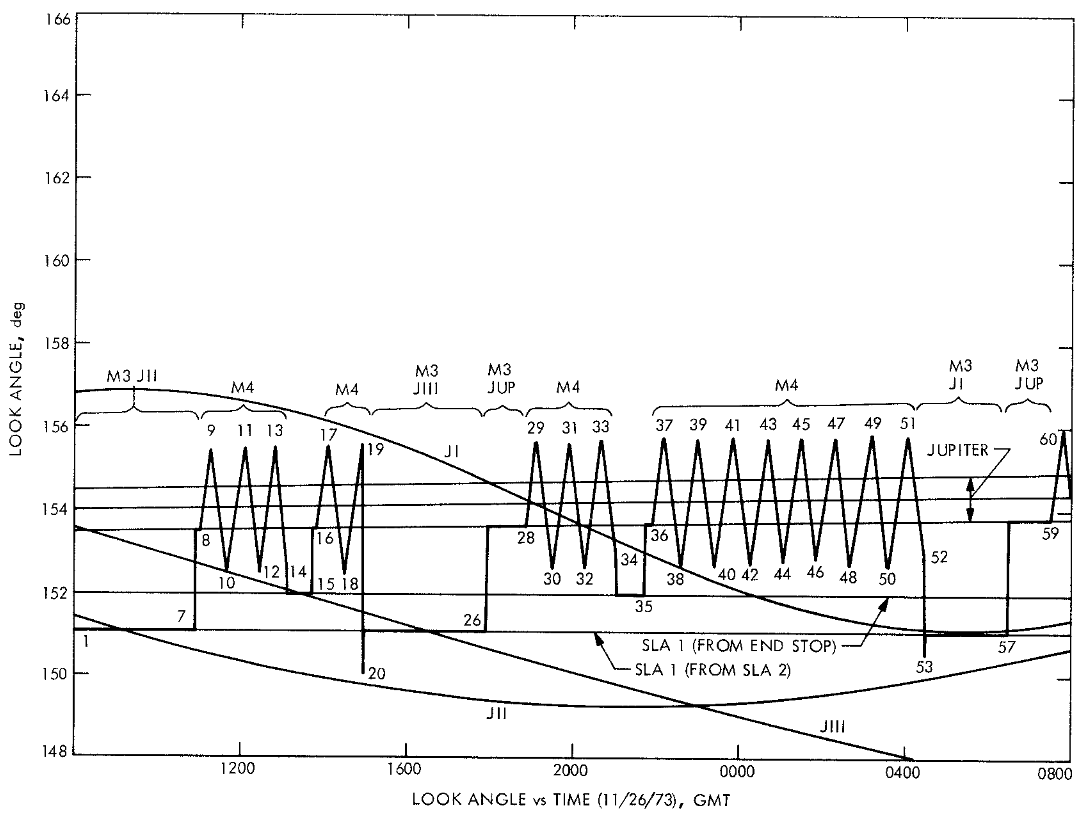

Fig. 2. Typical IPP 24-hour sequence

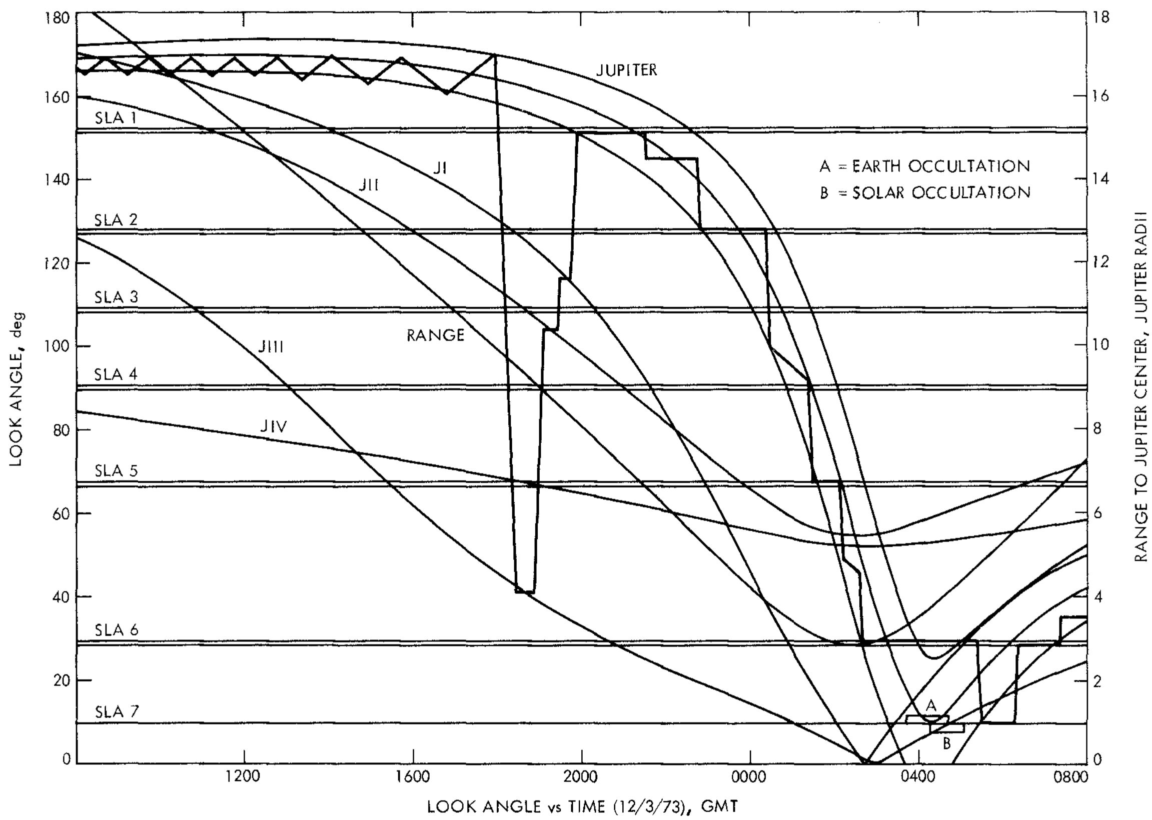

Fig. 3. Characteristic IPP periapsis sequence